

The Evolution of Hall C into a High Q^2 Hall

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Introduction

The role of Hall C at CEBAF is to support a broad and varied program of scientific initiatives that fall outside the programmatic capabilities of the Hall A and B facilities. The current experimental program include: high- q^2 inclusive electron scattering, photodisintegration, and (e,ep) reactions; electroweak physics; hypernuclear physics; and high-luminosity out-of-plane (e,ep) measurements. To mount such a varied program requires a highly flexible set of instruments. The present complement of instruments available or planned for Hall C includes a High Momentum Spectrometer (HMS) that serves as a hadron spectrometer for high- q^2 physics and as an electron spectrometer for inclusive scattering experiments plus a series of coincidence experiments utilizing "second-arm" spectrometers. To provide the necessary flexibility, the HMS has the capability of analyzing high-momentum particles (up to 7.4GeV/c), a large solid angle and momentum acceptance, and excellent trajectory reconstruction capability to the target; its momentum resolution is better than 10^{-3} . These capabilities provide an excellent match to the approved research program that includes the extensive use of cryogenic and polarized targets.

The "second arm" spectrometers for Hall C, each of which has been optimized for a different physics program, are constructed by various user-managed consortia. The first of these "second-arm" spectrometers was the Short Orbit Spectrometer (SOS). It is used in conjunction with the HMS for studies of the electroproduction of pions and kaons, and also for a variety of (e,ep) coincidence experiments aimed at the investigation of the energy and mass dependence of nucleon propagation in nuclei. The SOS will also be used in conjunction with a virtual photon tagging system for a first-generation hypernuclear spectroscopy system (HNSS). Later, the HNSS may be upgraded through the construction of a Kaon spectrometer having substantially higher resolution than the SOS, but with a lower maximum momentum capability and range.

Additional, second-arms have included the t_{20} deuteron transport line and polarimeter, the currently running G_{En} neutron detector array, a second G_{En} experiment with a neutron detector array and spin precession magnets, and the stand alone superconducting G^0 parity spectrometer.

Present Status of Hall C at Jefferson Laboratory

The base equipment has in operation for approximately three years during which 26 Ph.D. candidates have collected their dissertation data from 8 Hall C experiments. Check marks by the items listed below indicates operational apparatus or completed measurements.

Base instrumentation

- √ High Momentum Spectrometer, Short Orbit Spectrometer.
- √ LH_2 , LD_2 , solid target systems.
- √ I , E , position, and beamline polarimeter.

• Major Specialized Equipment Installations

- √ t_{20} deuteron channel installed, run and removed.
- √ G_{En} polarized target, detectors, ...

Calendar 1998 Activities

- √ First "major" experiment (t_{20}) successfully completed.
- √ E93-021 (Mack) " _ Form Factor" successfully completed.
- √ E91-003 (Jackson) " _ Electroproduction" successfully completed.
- √ ^3He , ^4He target system successfully operated.

- E93-026 (Day/Mitchell) “Charge Form Factor of the Neutron”.
 - √ Install polarized target system installed on Hall C pivot.
 - √ Magnetic chicane beamline/controls for polarized target installed.
 - √ Irradiation of polarized target material using “FEL” facility electron beam.

New Hall C Initiatives

- Short Term:
 - “Laser” beam energy measurement system under commissioning.
 - HNSS (Enge Split-pole & SOS) experiment installation and running in 1999.
 - Compton beamline polarimeter under design.
- Medium Term:
 - G_{En} (Madey/Kowalski) experiment installation and running 2000.
 - G_0 (E91-017) parity violation spectrometer system ~ 2001.
- Long Term: (to take Advantage of Accelerator Energy Upgrades)
 - Hypernuclear spectrometer system upgrade (new spectrometer or QDQ from NIKHEF).
 - 12GeV Super HMS - evolution of Hall C into high Q^2 Hall.

May 1998 Hall C Higher Energies Physics Workshop

On May 7, 1998 a pre-workshop attended by Hall C users and staff explored some of the areas of research possible with the future 12 GeV upgrade of CEBAF. The agenda of this meeting is given below.

Agenda - Hall C Higher Energies Physics Workshop - May 7, 1998

09:30 AM	J. DUNNE	J/Psi Production at Threshold
10:00	R. ENT	Electron-Proton Coincidences at High Q^2
10:45	A. LUNG	$X > 1$ Physics with a 12 GeV beam
11:15	O. K. BAKER	Spin Polarization in Kaon Electroproduction
11:45	D. MACK	The Pion Charge Form Factor
13:30	P. STOLER	Something about $N \rightarrow N^*$
14:00	J. MITCHELL	Inclusive Spin Structure Functions
14:45	R. ENT	Quark Hadronization Studies & Semi-exclusive Reactions
15:15	C. KEPPEL	Higher Twist and Large x Physics
15:45	L. TANG	Hypernuclear Studies
16:15	P. MARKOWITZ	Electroproduction Experiments with Septa
	R. Michaels	Parity Violation in e-d DIS as a Standard Model Test
	R. Micheals	Ratio d to u Quark Distributions from Parity Violating e-p DIS

The broad design goals for a Super High Momentum Spectrometer (SHMS) evolved from the consensus that developed among the users at the May 1998 Hall C Higher Energies Physics Workshop. Specifically, that a very high momentum, moderate resolution spectrometer will be required for most experiments envisioned for Hall C as the machine energy is raised significantly above 6 GeV. A careful review of the requirements of the experimental programs discussed at the Hall C Higher Energies Physics Workshop in May 1998 formed the basis for the specifications for the performance requirements. These requirements are given in Table 1.

TABLE 1

Super HMS (SHMS) - The Major New “Core” Equipment Required for ~12 GeV

- Basic Design Goals
 - ~12 GeV momentum capability.
 - ~5.5° minimum laboratory angle (with HMS at 10.5°).
 - ~25° maximum laboratory angle (HMS maximum ~85°).
 - ~3 msr acceptance.
 - Significant bending angle of $> 15^\circ$.
 - Appropriate and flexible detector package.
- For a “typical” coincidence experiment
 - Super HMS (max. 25°) is used in place of HMS (max. 85°)
HMS (max. 85°) is used in place of SOS (max. 140°)
 - SOS is either dismantled & removed ,

or
 - SOS could be used at angles of > 45 degrees with SHMS
on same side of Hall C.
 - With SHMS on the HMS side of the Hall SOS could operate
as before, but user would have to switch between SHMS and
HMS to obtain approximately the current angular coverage.

High q^2 Physics Program and Hall C Equipment Layout

The research program planned for the SHMS and HMS is broad and varied. It includes single-arm (inclusive) electron scattering experiments such as the measurements of the deep inelastic structure functions, nucleon propagation in nuclei as measured via the (ee'p) reaction, pion form factor measurements, and measurements such as color transparency studies involving the use of the (12 GeV capable) SHMS in coincidence with the (7.4 GeV capable) HMS spectrometer.

EXAMPLE: Inclusive Scattering from Nuclei at Large x and Q^2

The most direct probe of the quark degrees of freedom in the nucleus is via the deep inelastic structure functions in the scaling limit. The behavior of the structure functions in a nucleus for $x > 1$ (kinematically forbidden for the free nucleon) is unknown and the predictions vary considerably. The region $x > 1$ is also the kinematic domain where y -scaling of the quasielastic response can be investigated. By following the Q^2 evolution of the nuclear response, the transition from the y -scaling of quasielastic scattering to the x -scaling of deep inelastic scattering can be probed directly. To understand the kinematic range that can be explored at a 12 GeV CEBAF, consider the Q^2 vs. ν plot shown in Figure 1. For a 4 GeV beam (i.e. $\nu < 4$ GeV) only a tiny corner of the conventional deep inelastic region ($Q^2 > 1$ GeV and $W > 2$ GeV) can be explored. However, a fairly large area of the $x > 1$ region can be studied. With a 12 GeV beam a significantly larger area in the (Q^2, ν) plane can be probed, especially when actual rate estimates are considered.

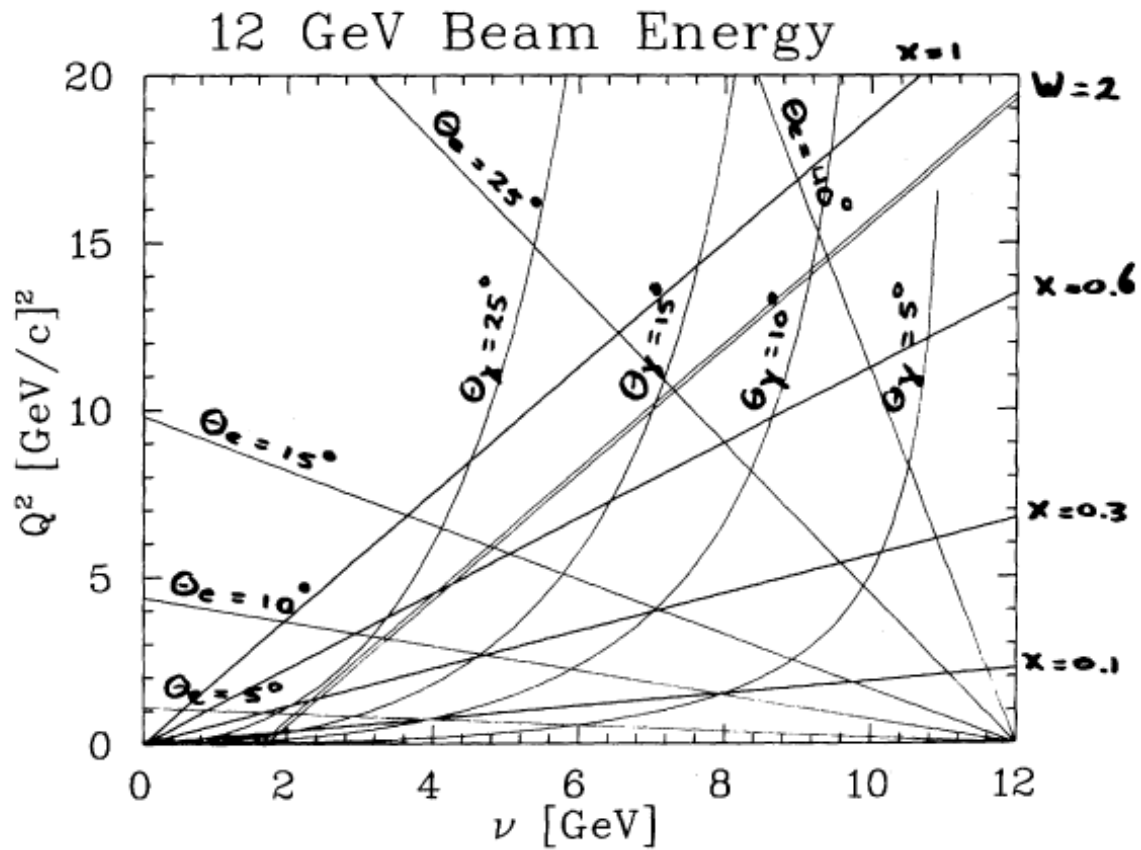


Figure 1. Plot of ν versus Q^2 for a 12 GeV electron beam.

The Super High Momentum Spectrometer (SHMS)

The Super High Momentum Spectrometer is considered by the Hall C user community to be the highest priority new instrument for fully exploiting the anticipated accelerator energy upgrades between 6 and 12 GeV. The very cost effective construction approach for the SHMS is outlined below. A schematic of the proposed SHMS is shown in Figure 2.

- Construction Approach
 - SHMS Dipoles:
 - Use “surplus” resistive dipole(s) (SLAC ESA 20 GeV dipoles)
 - Build “new” min. power consumption (lots of Cu) resistive dipoles.
 - Build “new” superconducting dipole(s).
 - Use proven HMS quadrupole design of Q1.

"Strawman" Super HMS

SHMS Basic Design Parameters

Max. Central Momentum	12GeV/c
Max. Solid Angle	3.0 msr
Momentum Acceptance	20%
Momentum Resolution	10^{-3} (FWHM)
Min. Scattering Angle	5.5°
Focal Plane Dimensions	60 cm x 60 cm

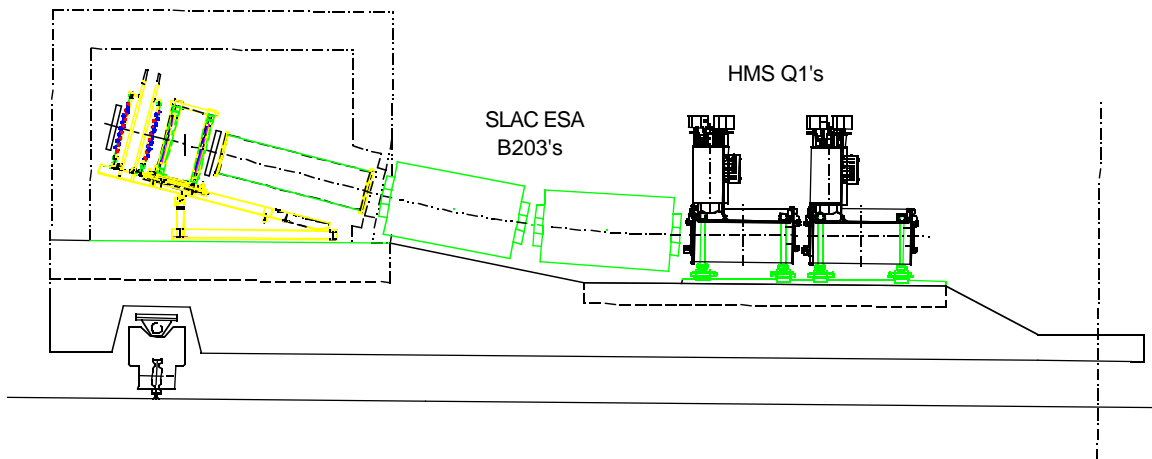


Figure 2. Schematic of proposed 12GeV Super High Momentum Spectrometer (SHMS).

The Ion Optical Design of the SHMS

The detailed evaluation of the experiments outlined above, together with the discussions at the 1998 Summer Workshop lead to the ideal performance goals given in Table 2 for the SHMS. In the subsections that follow we review existing spectrometer designs for high momentum spectrometers, consider possible choices for the optical elements of the spectrometer, and then present an overview of the design for the SHMS that emerged from these studies. Within this basic approach many optical choices can be made, both in number and type of elements. Some use many adjustable "knobs"; others do not. For this design, it was decided to use an approach which minimizes reliance on mechanics and "knobs" and substitutes a reliance on measurement of the actual performance of the system.

Possible Choices for the Magnetic Optic

There are still options within the design approach outlined above, such as the number of quadrupoles, their locations, and their strengths (or similarly for the dipoles). The first-order optics of a variety of systems were studied with TRANSPORT; these included possible QQQDD, QQDD, QQD, and QQD configurations. The focal plane tilt angle for the QQDD configuration of the SHMS is 4.2° .

TABLE 2

PERFORMANCE COMPARISON WITH OTHER SPECTROMETERS

Spectrometer ID	ESA	HMS	SHMS
Configuration	QQQDD	QQQD	QQDD
Max. Rigidity (kGm)	534	200	400
Central Momentum (GeV/c)	16	6	12
In - Plane Angle (mr)	22	44	26
Off - Plane Angle (mr)	54	165	55 - 112
Max. Solid Angle (msr)	1.0	10	2.3
Momentum Acceptance	20	20	20
Dispersion (cm/%)	2.8	3.9	2.5
D/M (cm/%)	0.8	1.2	2.7
Focal Plane Angle (degree)	1.75	4.5	4.2
Minimum Scattering Angle	6.5	12.5	5.5
Optical Length (in)	30.01	23.65	20.7
Momentum Resolution (FWHM)	2×10^{-3}	10^{-3}	10^{-3}
Focal Plane Dimension (CM2)	60 x 36	100 x 50	60 x 60
Max. Gradient of Quads (T/m)	9.5	7.5	8.0
Max. Dipole Central Field (T)	2.05	1.67	2.05
Sliding Distance (in)	N/A	0.4	1.0

Mechanical and Magnetic Design

Figures 3 and 4 show plan and elevation views in Hall C of the proposed SHMS. In the proposed QQDD design the quadrupoles are superconducting (copies of HMS Q1) while the dipoles are resistive magnets. Although, it is certainly possible to build new superconducting dipoles for this spectrometer, their already exist ideal resistive magnets at SLAC. Resistive dipoles, also, tend to be slimmer than their superconducting cousins, while the opposite is true for large quadrupoles. The desired physical characteristics of the dipole and quadrupoles are given in Table 2. The magnetic/physical properties of the dipoles are listed as well. The SHMS is designed to have a minimum closing angle of 5.5° with respect to the 0° beam line.

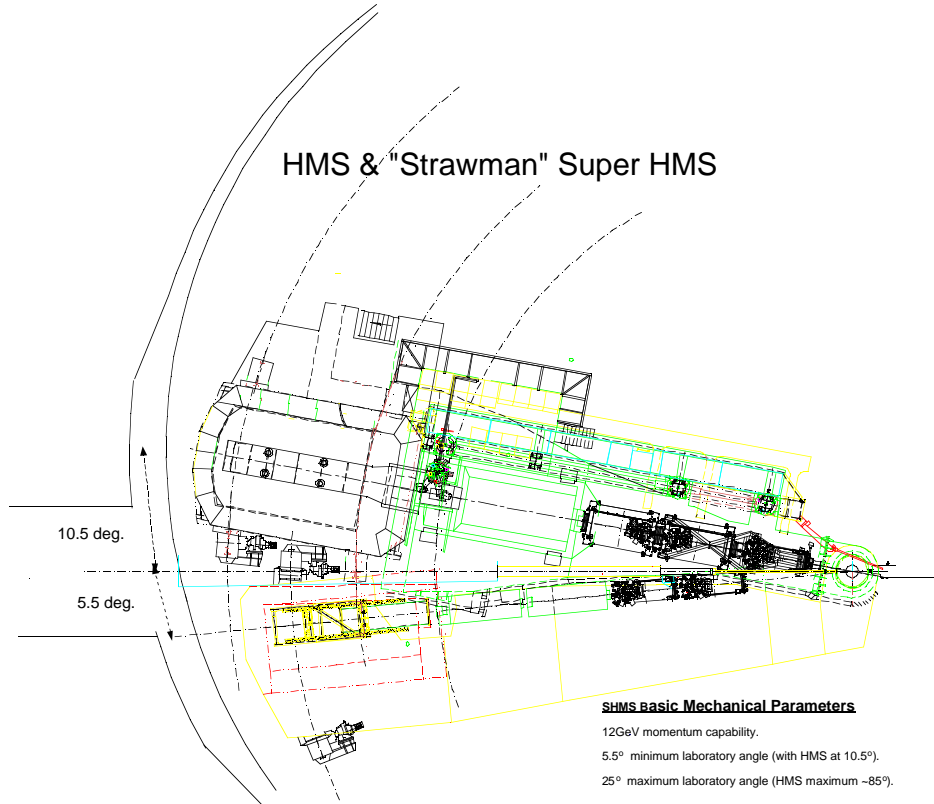


Figure 3. Plan view of SHMS and HMS at minimum opening angles with respect to the beamline.

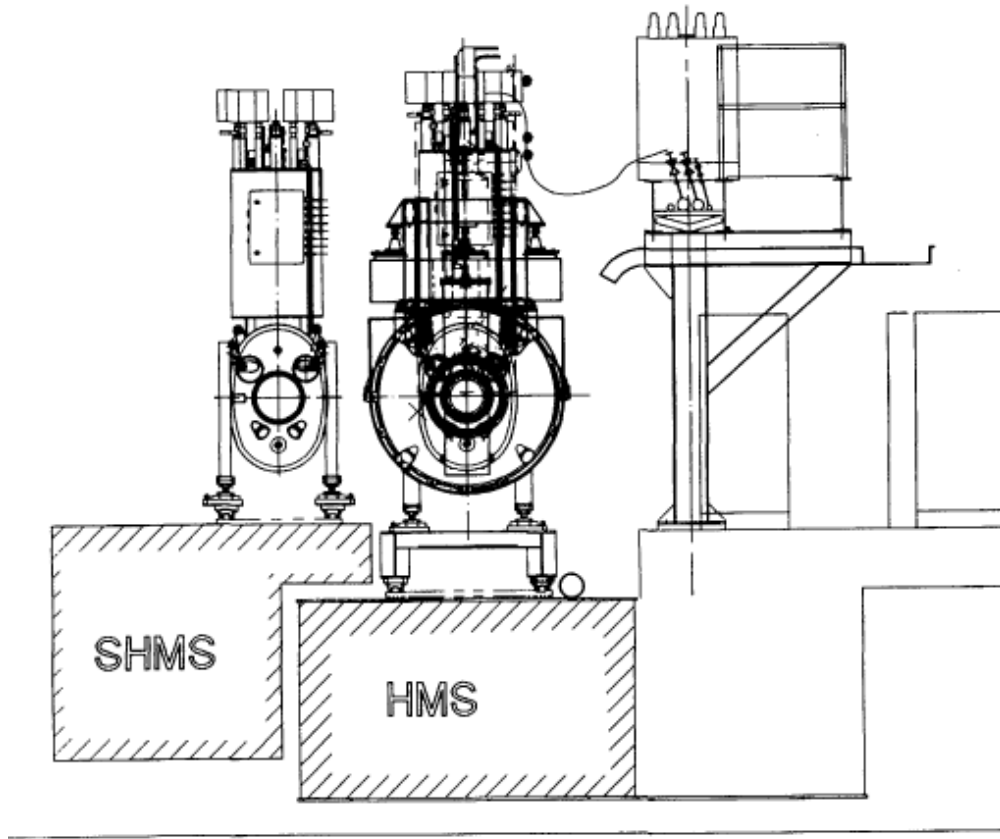


Figure 4. Elevation view of SHMS and HMS at minimum opening angles w.r.t. the beamline.

SHMS quadrupoles Q1 and Q2 are superconducting cold-iron quadrupoles identical to the first quadrupole of the Hall C HMS. This slim quadrupole is an excellent magnetic and mechanical match to the SHMS requirements. Magnetic effective length for the "quad" is 1.8 meters. The pole tip field is approximately 1.5 Tesla, a gradient of 605 gauss/cm and a pole tip radius of 25 cm. The warm bore for Q1 is 22 cm radius. Figure 5 shows a cross section of Q1/Q2. The inner tube is the beam vacuum surface, then moving outwards is the 70°K surface followed by the helium dewar. The coils are made from about 100 turns/pole of Fermi cable. The pole surfaces are hyperbolic in shape. This is a narrow quadrupole which is necessary to allow the 5.5° closing angle.

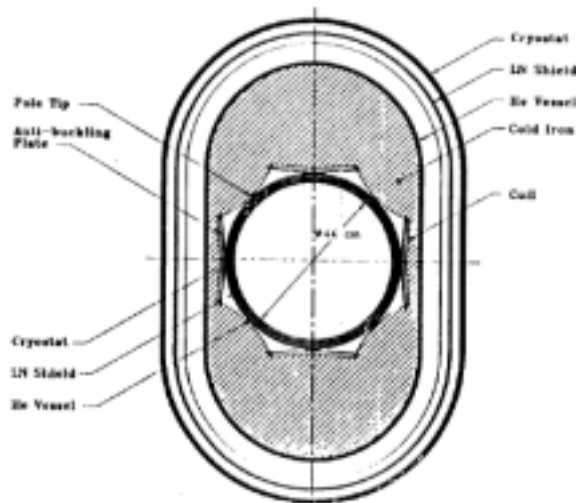


Figure 5. A cross section sketch of HMS quadrupole Q1.

Anticipated Performance of the QQDD Design

The degree to which the QQDD design has met the goals set forth in Table 1 are summarized in Tables 2 and 3. The overall anticipated performance from these early design studies of the proposed QQDD come remarkably close to meeting the rather ambitious design goals set for it. Figure 6 show the characteristics of the SHMS focal plane, while Figure 7 compares the anticipated imaging width versus momentum range in % for the SHMS design to that of the Halls A HRS and the Hall C HMS.

TABLE 3

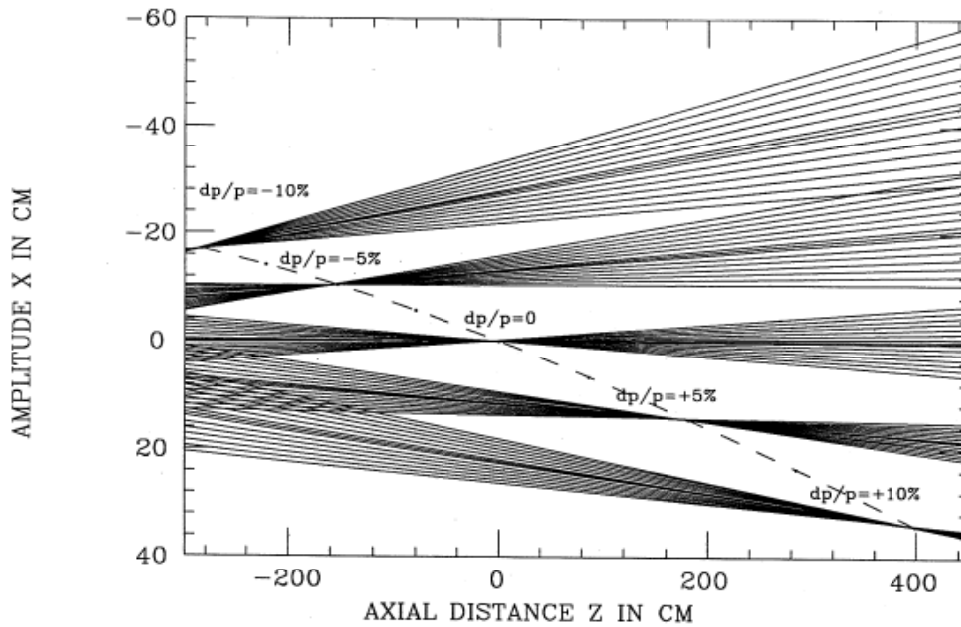
ACCEPTANCE V.S. IMAGING MODE

y-imaging mode	non-focusing		point-to-point		point-to-parallel	
Constraint	$R_{12} = 0$ only		$R_{12} = R_{34} = 0$		$R_{12} = R_{44} = 0$	
1 st drift (m)	4.64	3.64	4.64	3.64	4.64	3.64
p_0 (GeV/c)	12	12	9.72	8.63	10.35	9.11
$\Delta\Omega$ (msr)	0.98	1.19	1.56	2.19	1.62	2.25
Θ (degree)	5.5	8.0	5.5	8.0	5.5	8.0
D/M_x (cm/%)	2.7	2.3	3.0	2.7	2.9	2.6
θ_{\max} (mr)	13.0	15.3	11.7	13.0	12.2	13.4
ϕ_{\max} (mr)	24.1	24.8	42.5	53.5	42.5	53.5

ACCURACY OF RECONSTRUCTED OPTICAL PARAMETERS

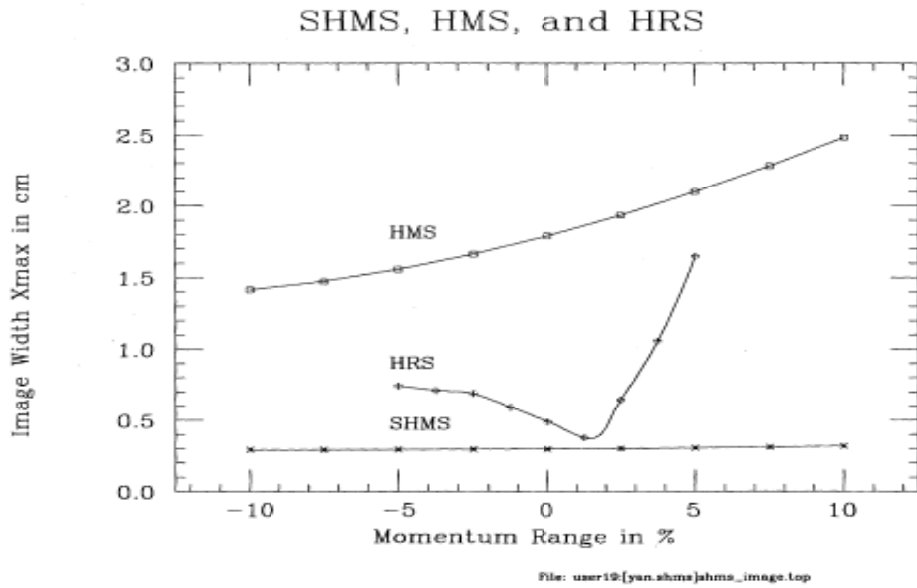
Momentum p	$\sigma = 1.68 \times 10^{-3}$	for 6 = -10%
	0.75×10^{-3}	for 8 = -5%
	1.02×10^{-3}	for 8 = 0%
	0.62×10^{-3}	for 8 = 5%
	1.24×10^{-3}	for 6 = 10%
In-plane angle θ	$\sigma = 0.92$ mr	
Out-plane angle ϕ	$\sigma = 3.04$ mr	
Transverse coordinate y	$\sigma = 8.7$ mm	

FOCI OF SHMS



5 momentum points SHMS Foci Projection on x-plane

Figures 6. The characteristics of the SHMS focal plane



Comparison of image width of SHMS, HMS, and HRS

The image widths are calculated by RAYTRACE high-order code referring the point source. The entire image width $dx = Mx \cdot dx_0 + dxf$, where dx_0 - the size of beam spot on the target, Mx - the first order magnification, dxf - image width of point source by RAYTRACE

The hardware resolution $R = dx/D$, D -dispersion

Figure 7. A comparison of the anticipated imaging width versus momentum range in % for the SHMS design to that of the Halls A HRS and the Hall C HMS.

Detector Package

The detector package for the SHMS should be a straightforward design using currently available technology. Its characteristics and elements are summarized in Table 4. The primary function of the detector package will be to identify relatively high energy electrons in a modest background of negative pions and measure their trajectories in the region of the SHMS focal plane. Some experiments will also use the SHMS to analyze high momentum protons, so the detector package provides some e/π separation as well.

TABLE 4

CHARACTERISTICS OF THE SHMS DETECTOR PACKAGE

ID	Location (m)	Length (m)	Active Area (cm ²)
Cherenkov	-3.4	3	70 x 55
MW01	-0.5	-	90 x 60
MW02	0.5	-	90 x 60
Shower Counter	0.8	0.6	90 x 60
Hodo	1.4	2.2	110 x 70
Total	6.5		

